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Comparison Study on Two Parameters Extraction Methods for Different PV Modules

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Abstract

For modelling a photovoltaic module, it is necessary to calculate the basic parameters which control the current-voltage characteristic curves that are not provided by the manufacturer. A numerical methods are time consuming and require long term chronological data that are not available in most developing countries, an improved mathematical model has been formulated by combining expository and numerical techniques to defeat the confinements of existing strategies. The values of the required input parameters of the model have been calculated analytically. The expression of the output current of the photovoltaic module was determined clearly by the Lambert W function and the voltage was determined numerically by the Newton-Raphson method. This paper displays a relative investigation of parameter estimation strategies dependent on the maker's information sheets for different photovoltaic (PV) module innovations. In this study, two methods of parameter estimation are used: an iterative method and an analytical method based on the Lambert W function. These methods allow us to calculate the five parameters unknown under standard test conditions (STC) for two types of photovoltaic modules: multi-crystalline and thin films technology.

Keywords: *PV modules, Iterative methods, Lambert-W function methods, Parameter Extraction, Performance I–V Curves*

INTRODUCTION

The choice of the model that carefully simulates the properties of PV modules is very important. It is known that the model is accurate if it corresponds to the I-V data measured under all operating conditions.

Over the years, several models are introduced – among the more popular ones are the circuit based single diode [1] and the two diode model [2]. The latter, although more extensive in calculation is preferable because it's I - V characteristics are very similar to the behavior of a physical module [2].

The parameters of the two-diode model can be calculated using the Newton-Raphson. However, due to the complexity of the two-diode model (which requires the solving of seven parameters), only several papers are reported to go along this approach [3-6]. In most cases, some rounding types are needed to ensure that the model can be controlled analytically As a result, the accuracy of the solution is compromised.

The single-diode model is the simplest because it has a current source parallel to a diode. This model is enhanced by the inclusion of an RS series resistor.

An alternative approach, with the aim to reduce the complexity of calculation and reduced number of iterations is presented in [7]. It is based on the use of Lambert W Function which gives the explicit result of the current and voltage equations. This approach provides a unique equation for calculating the PV current and avoids the need for an iterative solution [7]. The transcendental form of current equation of Single diode model which leads to I-V result gives the iterative mathematical procedures (such as Newton's method)is difficult to employ for reproducing the PV cell's characteristics. When you want to model a larger PV array (a large PV array composed of PV modules connected in series and in parallel) using this transcendental equation, in which each cell (or module) is individually described as an equation, the task becomes extremely complicated, time consuming and requires sophisticated tools, fast and advanced processors. This limitation can be overcome by the Lambert-W function for modelling a photovoltaic generator.

Here the equation of the PV cell is expressed in an explicit formula of both voltage and current equation [8]. The Lambert W Function is grant the lineal correlation between current and voltage of module, therefore, it decrease the computation time.

This paper proposes two simulation methods, which can predict the I–V characteristics of large PV arrays. It can be used to study the impact of temperature and irradiance variation. The simulation is implemented by MATLAB programming. This paper presents a review of and a comparison between iterative and the Lambert W Function methods based on single diode model of parameters extraction for different technologies PV solar module.

Materials and Methods

Iterative method:

The single-diode electric circuit is the equivalent photovoltaic cell in this article. Two different models drawn from the equivalent electrical-circuit are studied: namely four- and five-parameter models.

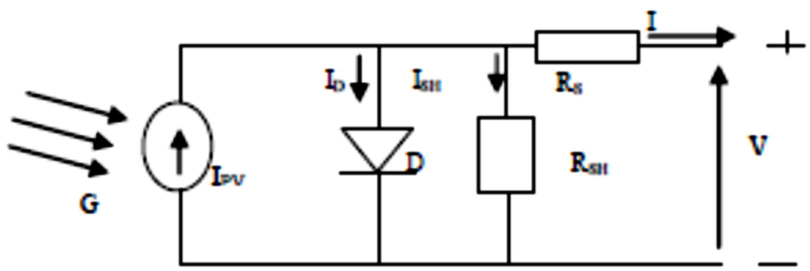


Figure 1: *PV-cell equivalent-circuit models: single-diode model [9].*

An output current equation of I-V characteristic using this model can be written as:

$$I = I_{pv} - I_0 \cdot \left(\exp\left(\frac{V + R_S . I}{V_T} \right) - 1 \right) - \left(\frac{V + R_S . I}{R_{sh}} \right) \quad (1)$$

Where

I_{pv} Photocurrent

I_0 Cell saturation current

R_{sh} Shunt resistance

R_s Series resistance

V_T the thermal voltage (V_T=a.Ns.k.T/q)

N_s Number of cells in series

a Ideal factor of the PV diode

q Electron charge (1.60281×10^{-19} C)

k Boltzmann's constant=1.38066×10^{23} J/K

T Cell operating temperature

As given in Eq. (1), the five-parameter model is an implicit non-linear equation, which can be solved with a numerical iterative method such as Newton Raphson method [10]. However, this requires a close approximation of initial parameter values to attain convergence. Alternatively, the parameters may be extracted by means of analytical methods.

Some of the analytical methods are studied elsewhere [10-13].

The five parameters I_{pv}, I_o, R_s, R_{sh}, and m are calculated at a particular temperature and solar-irradiance level from the limiting conditions of V_{oc}, I_{sc}, V_{mp}, I_{mp} and using the following definitions of R_{so} and R_{sho}:

$$R_{s0} = -\left.\frac{dV}{dI}\right|_{V=V_{oc}} \quad (2)$$

$$R_{sh0} = -\left.\frac{dV}{dI}\right|_{I=I_{sc}} \quad (3)$$

Where R_{s0} and R_{sh0} are the reciprocals of the slopes at the open-circuit point and short-circuit point, respectively. The values of these resistors are generally not provided by module manufacturers. The other parameters are calculated as follows. The following equations are used to calculate the five parameters required.

$$I_{pv} = I_{sc}\left(1+\frac{R_s}{R_{sh}}\right) + \mathrm{I}_0 \cdot \left(\exp\left(\frac{I_{sc}.R_s}{V_T}\right)-1\right) \quad (4)$$

$$I_0 = \left(I_{sc} - \frac{V_{oc}}{R_{sh}}\right).\exp\left(-\frac{V_{oc}}{V_T}\right) \quad (5)$$

The value of the diode ideality factor (a) may be arbitrarily chosen. In many researches, the authors discussed the methods of estimating the correct value of this constant. Usually, 1 ≤ a≤ 2 and the chosen value depend on other parameters of the I–V model. As it's given in [14], there are different opinions about the best way to choose (a). Because (a) expresses the degree of ideality of the diode and it is totally empirical, any initial value of (a) can be chosen in order to adjust the model.

The R_s and R_{sh} resistances are calculated by iterative methods. The relation between R_s and R_{sh}, may be found by making the maximum power calculated by the I–V model, equal to the maximum experimental power from the datasheet ($P_{max,m} = P_{max,e}$) at the (V_m; I_m) point. In the iterative process, R_s must be slowly incremented starting from $R_s = 0$ and for every iteration, the value of R_{sh} is calculated simultaneously:

$$P_{max,m} = V_{mp} \times \left\{ I_{pv} - I_0 \cdot \left(\exp\left(\frac{V_{mp}+R_s.I_{mp}}{V_T}\right)-1\right) - \left(\frac{V_{mp}+R_s.I_{mp}}{R_{sh}}\right) \right\} = P_{max,e} \quad (6)$$

$$R_s = R_{s0} - \frac{V_T}{I_0}\exp\left(-\frac{V_{oc}}{V_T}\right) \quad (7)$$

$$R_{sh} = \frac{V_{mp}+R_s.I_{mp}}{I_{pv} - I_0 \cdot \left(\exp\left(\frac{V_{mp}+R_s.I_{mp}}{V_T}\right)-1\right) - \frac{P_{max,e}}{V_{mp}}} \quad (8)$$

The initial condition for the shunt resistance R_{sh} can be found when considering the initial value of R_s=0 [15, 16]

$$R_{sh,min} = \frac{V_{mp}}{I_{sc} - I_{mp}} - \frac{V_{oc} - V_{mp}}{I_{mp}} \quad (9)$$

In the proposed iterative method, the series resistance must be slowly incremented starting from a null value. For adapting the I-V curve to correspond the cell reference condition requires searching the curve for several values of series and equivalent shunt resistances. The Newton–Raphson method was used in the proposed iterative method due to the ability to overcome undesired behaviours [17].

The Explicit single-diode model using the Lambert W- Function

A PV cell of current equation mathematically solved by the Newton's Raphson method is difficult to employ the Large PV structure [8]. When reach the level of entire PV structure, the difficulty solving a Newton's method in large PV array because all cell is individually described as one equation, so the task becomes extremely complicated, rising the convergence issues. This limitation can be beat by the Lambert-W function for modelling a photovoltaic generator used to the explicit results of current and voltage equations (fig. 2). The Lambert W Function W(x) is defined as equation (11) [18-20].

If we make the following change of variable:

$$x = \frac{V_{mp}+I_{mp}.R_S}{a.N_S.V_T} \quad (10)$$

The analytical solution based on the use of the Lambert W function, which is the solution of the equation:

$$f(x) = x.e^x \quad (11)$$

The R_{sh} is a function of R_S as shown in this equation:

$$R_{sh} = [V_{mp} + I_{mp}.R_S]/(I_{PV} - I_{mp} - I_0 \left[exp\left(\frac{V_{mp}+I_{mp}R_S}{a.N_S.V_T}\right) - 1\right] \quad (12)$$

Then the series and parallel resistances can be written as follows:

$$R_s = \frac{x.a.N_S.V_T - V_{mp}}{I_{mp}} \quad (13)$$

$$R_{sh} = \frac{x.a.N_S.V_T}{I_{PV} - I_{mp} - I_0\,[exp(x) - 1]} \quad (14)$$

Where x's expression is given in Eq. (15). The value obtained by (15) is substituted in (13) and (14) to deduce the values of R_{sh} and R_S.

$$x = \text{Lambert W}\left[\frac{V_{mp}.(2I_{mp} - I_{PV} - I_0)\left[exp\left(\frac{V_{mp}.(V_{mp} - 2a.V_T)}{(a.N_S.V_T)^2}\right) - 1\right]}{a.N_S.V_T.I_0}\right] + 2\frac{V_{mp}}{a.N_S.V_T} - \left(\frac{V_{mp}}{a.N_S.V_T}\right)^2 \quad (15)$$

The mathematically relation the equation (11) is applied to equation (1) in order to obtained the equation for the cell gives the explicit results of current and voltage equation. By solving equation (1) with the Lambert W method the equation of the output current as the function of output voltage as given in equation (16) [21].

$$I = -\frac{V}{R_S + R_{sh}} - \frac{LambertW\left(\frac{R_{sh}(R_S.I_{pv} + R_S.I_0 + V)}{a.V_T(R_S + R_{sh})}\right)}{R_S} + \frac{R_{sh}(I_0 + I_{pv})}{R_S + R_{sh}} \quad (16)$$

The diode reverse saturation current is assumed to vary with temperature according to [22, 23]. Its expression is given by:

$$I_0 = I_{pvn}\ .\exp\left(-\frac{V_{ocn}}{a.N_S.V_{Tn}}\right) - 1 \quad (17)$$

The ideality factor a is calculated by:

$$a\left(K_V - \frac{V_{oc}}{T_n}\right) / a.N_s.V_{Tn}\left(\frac{K_i}{I_{pvn}} - \frac{3}{T_n} - \frac{E_g}{k.T_n^2}\right) \quad (18)$$

RESULTS AND DISCUSSION

Accuracy test

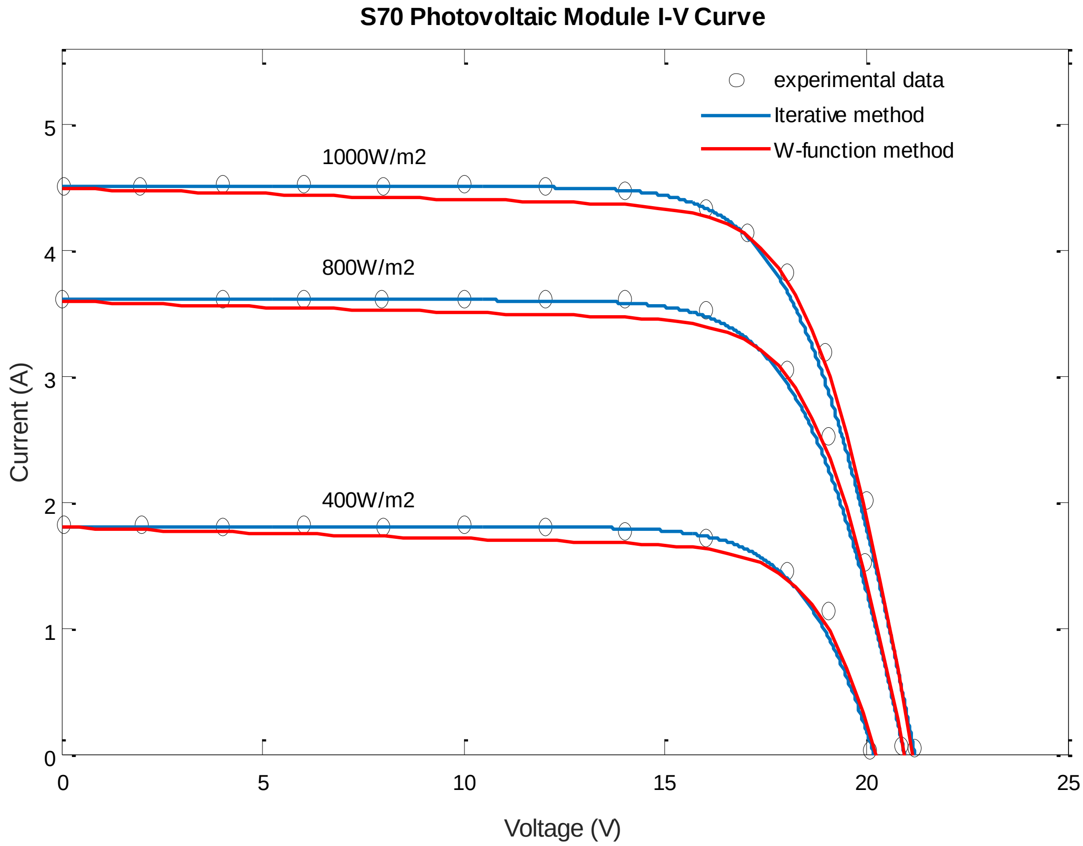
The equations of the previous section were implemented in MATLAB/Simulink environment to simulate, evaluate and test the three models mentioned above for two different modules, namely, S70 and ST40. The datasheet parameters specified in STC are given in Table 1.

Table1: *Specification of the PV modules*

Modules	Isc (A)	Voc (V)	Imp (A)	Vmp (V)	Ki(Isc) (mA/°C)	Kv(Voc) (mV/°C)	Ns
Poly-crystalline Shell S70	4.5	21.2	4.12	17	2	-76	36
Thin-Film Shell ST40	2.68	23.3	2.41	16.6	0.35	-100	36

Fig. 3 show the I-V characteristics compared with measured data extracted from each PV module's datasheet, for different irradiance levels at 25°C. It is observed that the output currents of the module strongly depend on the solar irradiance, since they vary linearly with it.

When the irradiance decreases, the intensity of the short circuit current I_{SC} also decreases, while the open circuit voltages V_{OC} undergo only a small variation. It is noted that the I-V characteristics of the two models show good agreement with the measured data for the crystalline module, with the exception of the W-function method for thin-film module around V_{OC} for low irradiance. It can also be observed that even in the case of low radiation, the accuracy of the iterative method is preserved.



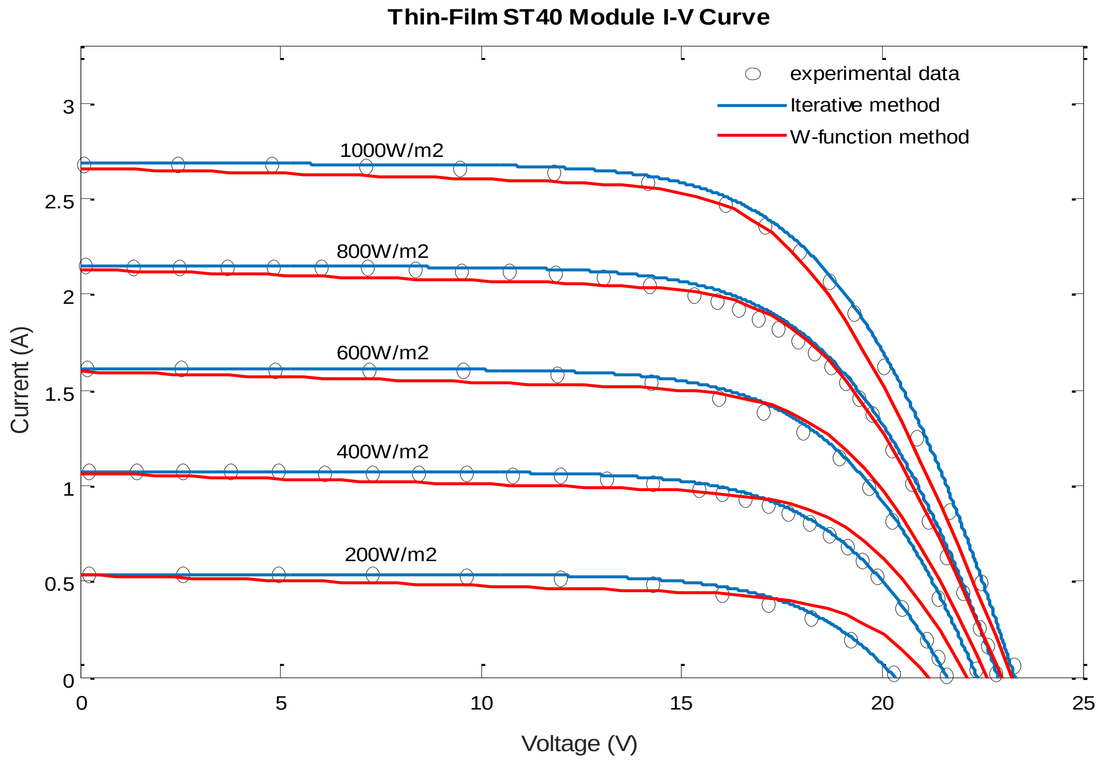


Figure 3: *The I-V characteristics of two modules at varying irradiance.*

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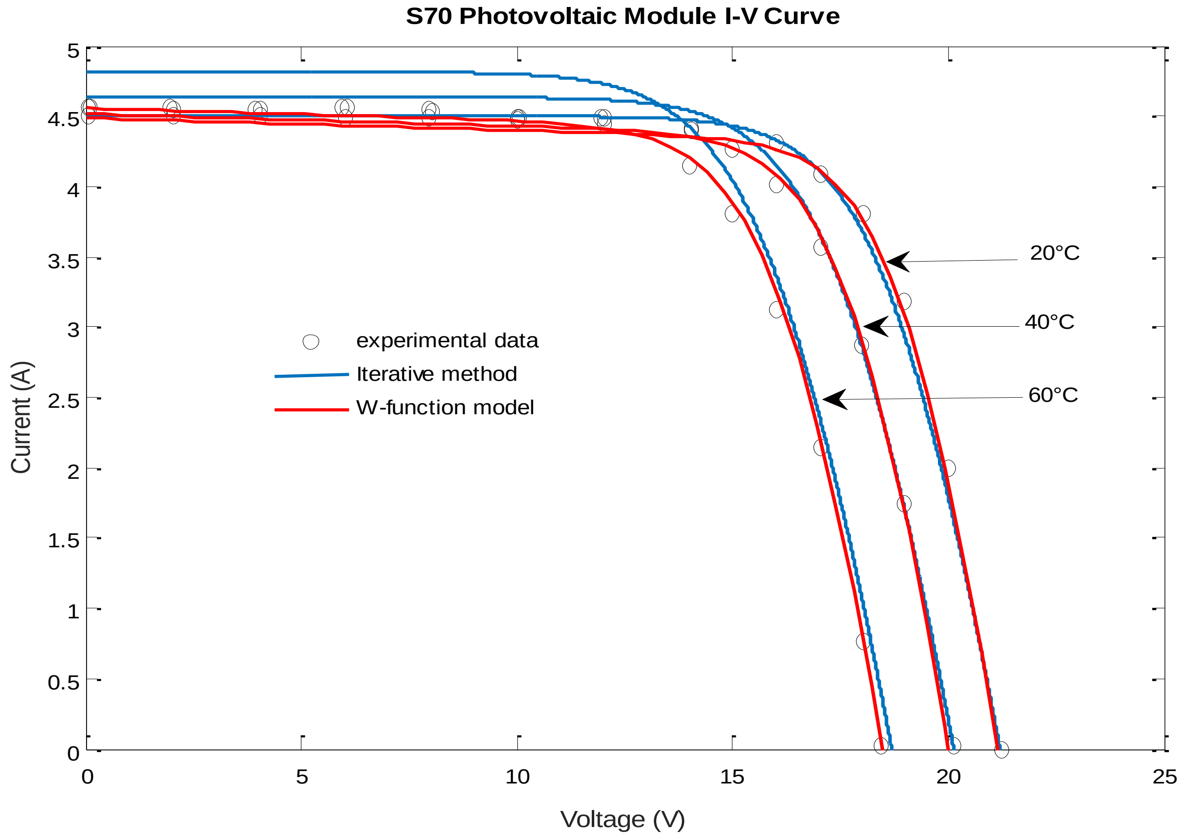


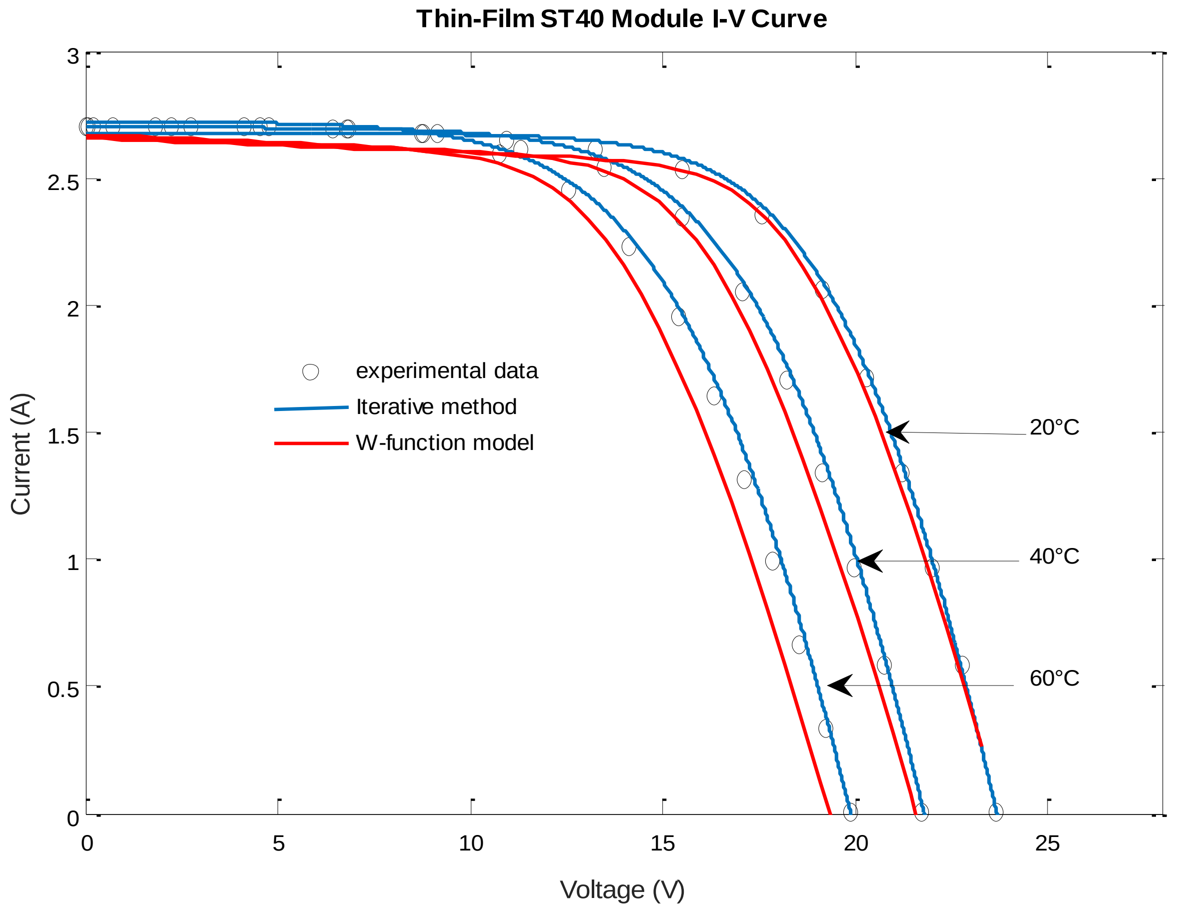


Figure 4: *The I-V characteristics of two modules at varying temperature.*

The temperature is a very influential parameter on the behavior of PV modules since they are exposed to the sun. Fig.4 shows the reconstructed three models' I–V characteristics. These I-V characteristics are compared with measured data extracted from each of the PV module's datasheet, for different temperature levels and at a fixed irradiance of 1 kW/m^2. Note that the effect of temperature on short circuit current is the same for all models. On the one hand, this basically shows that there is minimal dependence between I_{SC} and temperature changes. On the other hand, V_{OC} undergoes a remarkable decrease. It is observed that at temperatures around STC, the models have similar behaviour for all models. However, as the temperature increases, the Lambert W function method's characteristic tends to a slight deviate from the others for thin-film module.

Table 2: *The estimated parameters of S70 using three models at STC*

models	***Poly-crystalline S70***	
	Iterative method	***W-function model***
Ipv	***4.5***	***4.5***
a_1	***1.2***	***1.02***
Rs	***0.22***	***0.3279***
Rsh	189.0262	***113.424***
Io	***2.297e-8***	***7.446e-10***

Table 3: *The estimated parameters of ST40 using three models at STC*

models	***Thin-Film (ST40)***	
	Iterative method	***W-function model***
Ipv	***2.68***	***2.68***
a_1	***2***	***1.23***
Rs	1.51	***1.435***
Rsh	266.5478	***174.531***
Io	***9.122e-6***	***3.415e-09***

Table 2, 3 shows the parameters estimated for three modules. The values these parameters (R_S, R_{sh}, a, I_0 and I_{PV}) are estimated using three models. Certainly, the similarity of the results between these models is noteworthy and the differences have no appreciable influence on the simulated I-V characteristics at STC.

Statistical analysis

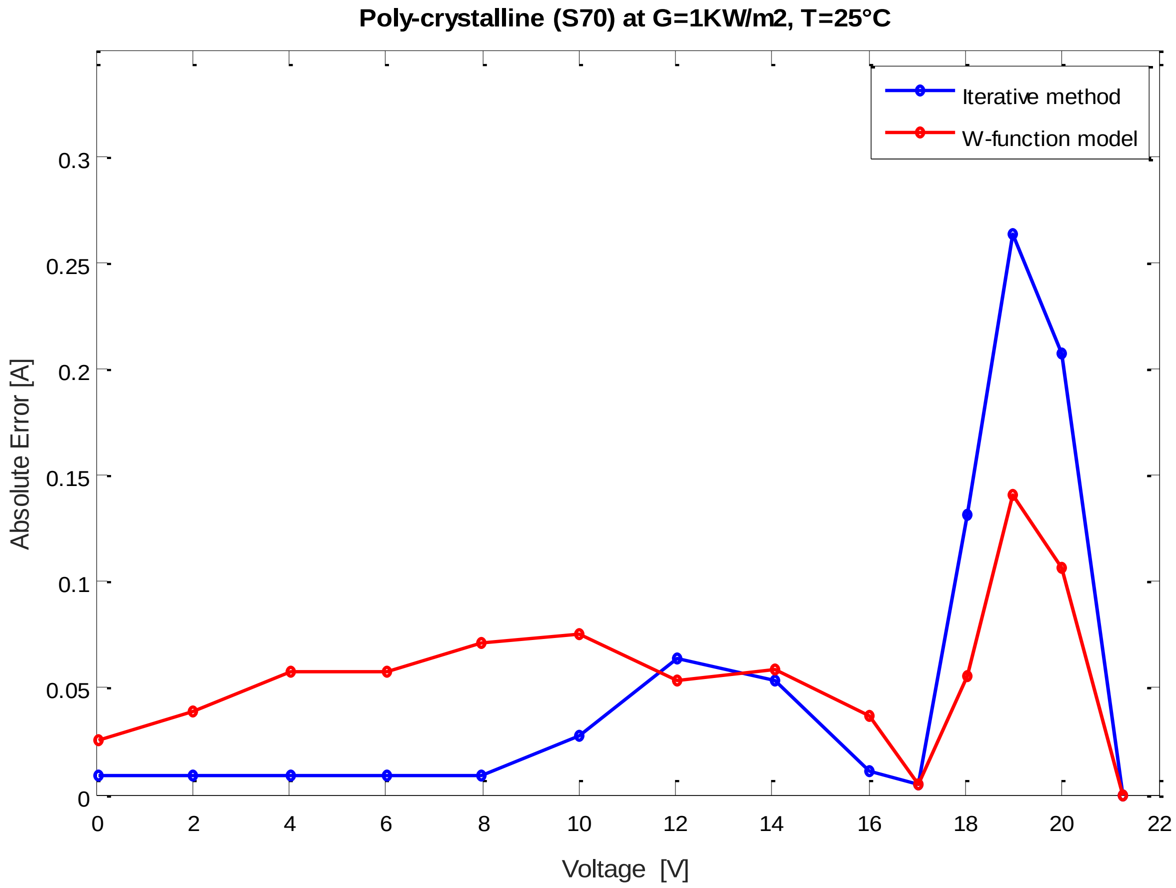
Since the efficiency and market share of multi crystalline and mono crystalline type panels are comparatively high, the authors validated their method only with different type modules.

To provide thorough evaluation, data corresponding to the above mentioned panels are Taken from manufacturer's datasheet and I-V curves are matched with the simulation results obtained using three models. Further, to know the quality of the curve fit between these models values to the experimental data, statistical analysis is carried out by measuring Individual Absolute Error (IAE) and Relative Error (RE) values. The IAE and RE values are calculated by using the mentioned formula.

Individual Absolute Error

$$(\text{IAE}) = \left| I_{\text{measured}} - I_{\text{estimated}} \right| \quad (19)$$

$$E_{relative}\,(RE) = \left(\frac{\left| I_{\text{measured}} - I_{\text{estimated}} \right|}{I_{\text{measured}}} \right) * 100 \quad (20)$$



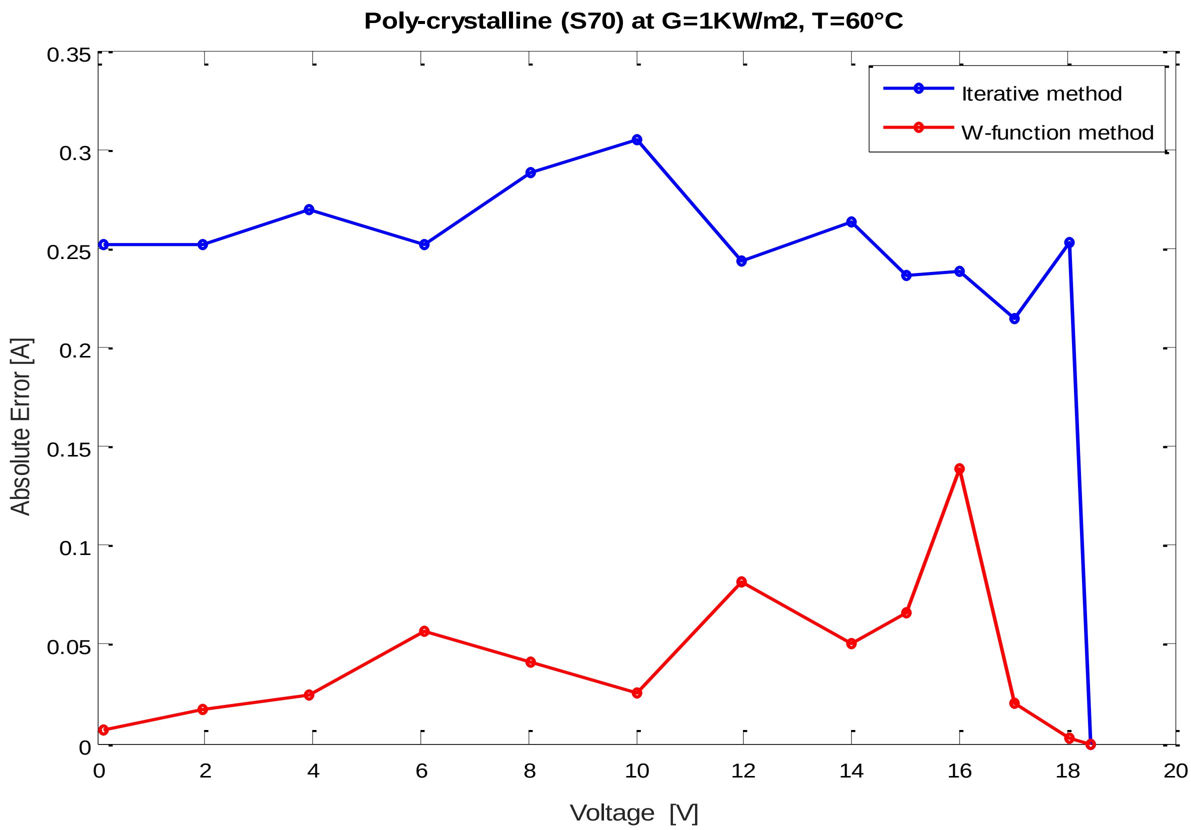
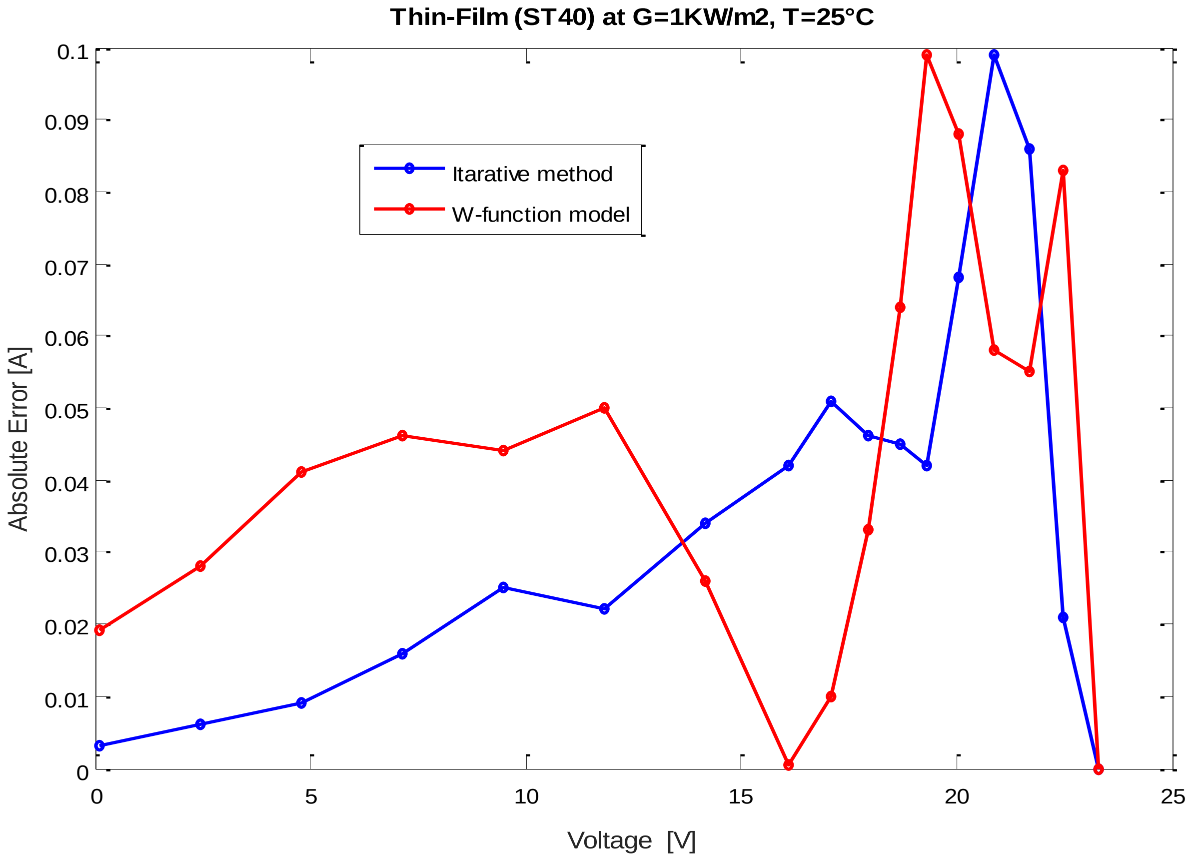


Figure 5: *Absolute error for multi-crystalline S70.*



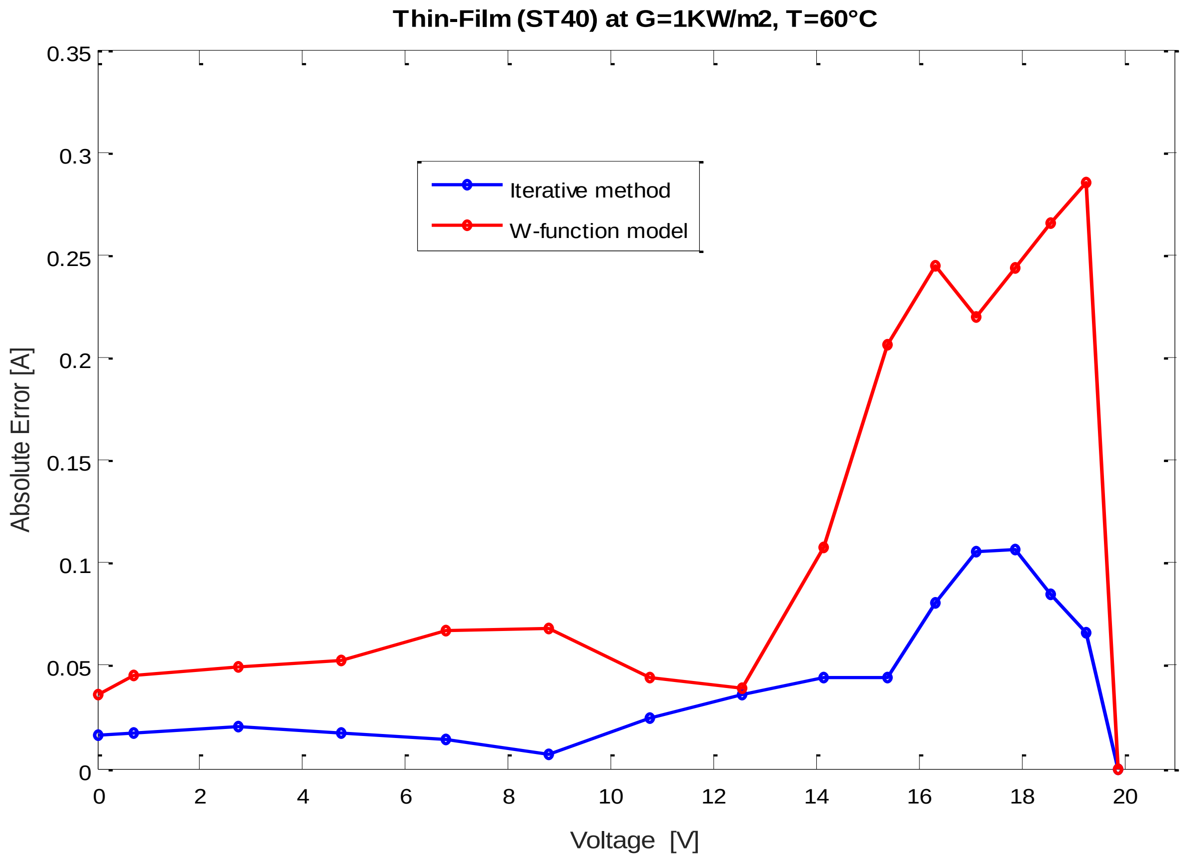


Figure 6: *Absolute error for Thin-Film ST40.*

Fig. 5, 6 show the absolute errors of I–V characteristic shown in Fig. 3, 4 for S70 and ST40 PV modules.

The absolute errors of the double-diode model are close to that of the W-function model at STC conditions for poly-crystalline (S70). It is worth mentioning that the absolute errors of the W function method for solar cells are far less than that of the iterative method at the high temperature conditions, and for thin-film (ST40), the absolute errors of the iterative method are less than that of the other method at all the conditions.

CONCLUSION

In this work, two parameter estimation methods existing in the literature are described and have been verified by simulation and measured data, which were extracted from datasheet I-V characteristics. The method that best approximates the I-V characteristics given in the PV modules' datasheets of S70 module is the Lambert W-function method. As for the ST40 module, it's shown that the most accurate method of parameter estimation is the iterative method. The differences between the two estimation methods have no appreciable influence on the simulated I-V characteristics under varying environmental conditions. In particular, excellent accuracy exhibited at high irradiance and low temperature conditions for all methods.

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